International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 4, Aug 2018, 803-818

ANALYTICAL INVESTIGATION OF BUCKLING BEHAVIOR OF HONEYCOMBS SANDWICH COMBINED PLATE STRUCTURE

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ABSTRACT

The applications of honeycomb structure plate are very important, since its structure have high strength in addition to the low weight. Therefore, these structures are used in the multi-important application, where, more its application is applied to buckling load in addition to other loads. Thus, it was necessary to highlight the buckling behavior of its structure. There, in this research, a suggested analytical solution to evaluate the critical buckling load of honeycomb sandwich plate structure combined from honeycomb part and upper and lower sheet plate parts. Then, the included results evaluated the mechanical properties of honeycomb part by analytical investigation and buckling load of sandwich plate structure with various parameters effect by the analytical and numerical investigation. The analytical work included the evaluation of the buckling load of a simply supported plate by driving the general equation of buckling the orthotropic plate with buckling load in an x-direction. Also, the results of simply supported honeycombs plate structure were evaluated by the numerical investigation, by using finite element method, ANSYS program Ver. 15, for various honeycombs core size effect. Therefore, a compare between the results were evaluated analytically and numerically of buckling load are presented to show the agreement between the two techniques were used. Where, the comparison of the analytical and numerical results showed a good agreement of results with a maximum error about (2.24%). Finally, the results showed that the buckling load is modified by increasing the honeycomb core size.

***KEYWORDS:** Buckling Analysis, Honeycomb Plate, Honeycomb Buckling, Finite Element Buckling & ANSYS Buckling*

Original Article

Received: Jun 10, 2018; **Accepted**: Jul 09, 2018; **Published**: Jul 31, 2018; **Paper Id.**: IJMPERDAUG201883

INTRODUCTION

The honeycomb sandwich structures are used to get the strength with high value to weight ratio of plate structure, [1]. Therefore, due to the best properties of the honeycomb structure, high strength to weight ratio, they were used in multi-application in engineering structure as an aerospace application. Where, the manufacture of honeycomb sandwich structure included the covering of the honeycomb part by upper and lower sheet plate. There, the upper and lower sheet plate could be used as metal or non-metal materials, [2]. Also, the honeycomb sandwich structure can be made from various materials types as metal, ceramic, composite materials etc. The application of honeycomb structure in engineering leads to supply different loads on the plate. There, one of these loads are the compression load, then, the compression load causes a production of linear elastic deformation of plate structure due to bending behavior of plate. Then, by increasing the compression load on the sandwich plate structure a buckling load is produced on the plate and then a production of bending behavior on it will be shown [3].

Many studies were presented on the honeycomb sandwich such as mechanical properties, bending behavior, vibration and other behavior of beam or plate honeycomb sandwich with various techniques are

used.

At (1999), J. K. Paik et. al., [4], presented the effect of various honeycomb sandwich structure parameters on strength properties of the plate. Where, the investigation included using two techniques, to evaluate the strength of plate structure, are a theoretical investigation and experimental work. In addition, the investigation includes the analysis of the multi mechanical behavior of sandwich plate structure as the bending and buckling behavior of aluminum panels. Also, the investigation included the discussing of the failure behavior of a panel. Then, at (2004), G. A. Kardomateas et. al., [5], presented an investigation of simply column buckling for sandwich and composite with the effect of involved thickness. Thus, the investigation included analysis of the buckling behavior by using Haringx and Engesser formulas, in addition to, using other formulas for direct column buckling. Where, the results included the analysis of three dimension solution for elastic behavior by using the finite element method.

After this, at (2010), M. O. Kaman et. al., [6], presented the failure behaviors of core honeycomb for panels structure. Where, the investigation included the evaluation of the critical buckling load of panel structure by using numerical technique and experimental work. Thus, the results included the investigation of the effect of core honeycomb size dimensions on the buckling behavior of the structure. In addition, at (2012), many researchers presented studies of the honeycomb structure with various behaviors by different techniques and parametric effect. Where, B. Saraswathy et. al., [7], presented analytical modeling of three dimension geometry for core honeycomb structure by using the finite element method. Also, the nonlinear transient modeling is presented by using of Fast Fourier Transformation formulation. Where, the results included evaluation of the natural frequency and response of honeycomb with various core size effect. Then, S. S. Hayaldar et. al., [8], investigated the core size effect on the natural frequency of honeycomb structure by using experimental and numerical techniques, with using finite element method, for various plate structure supports. Also, A. Boudjemai et. al., [9], presented in the same year the multi-design of honeycomb panel structure. Where, the investigation included the evaluation of the frequency model of clamped-free honeycomb panel supported with various techniques. Therefore, the techniques used to evaluate the results were the experimental work and the numerical investigation by finite element method, and then comparison the results was done.

At (2015), A. Bentouhami et. al., [2], investigated the effect of buckling behavior of core component under compression load. Where the investigation included the estimation of the buckling load for core by two techniques, the first, was the experimental technique and the second was the numerical investigation, and then, a comparison of the results together was done. Where, the buckling load was evaluated of the core including investigation of the effect of the used materials and density core on the load. There, the presented results showed that the critical buckling load increases with increasing of the core density. Also, G. Sakar et. al., [10], presented experimental and numerical investigations of free vibration behavior for a honeycomb structure. Where, the results included the natural frequency of the honeycomb sandwich with an effect of sheet plate thickness and honeycomb structure size.

Also, at (2016), Muhsin J. Jweeg, [11], presented an analytical investigation of vibration characterization for honeycomb sandwich plate with various honeycomb and sheet plate parts parameters effect. Where, the results included the evaluation of the natural frequency of the plate by an analytical solution and then a comparison with the numerical investigation was done, it was evaluated by using the finite element method. Where, the results showed that the natural frequency of honeycomb structure will be increased with increasing of the honeycomb core parts.

Finally, at (2018), A. Muc et. al., [12], investigated the buckling and strain of honeycomb sandwich shell panel structure by experimental and numerical techniques. Where, the results included investigation of the linear and nonlinear behavior for both two dimensions and three dimensions structure of shell with various core parametric effect.

In addition, many applications of engineering structure included the using of composite and sandwich structure as beam, plate and shell are used in a mechanical engineering field from many researchers. Thus, at the year from (2011 to 2018), as presented in [13 to 28], showed various applications of composite and sandwich structures at vibration characterization, buckling behavior, static behavior, and fatigue investigation fields. Where, the papers presented investigations of its application by various techniques as experimental, numerical (by using finite element method) and analytical solution of problem (by derive and solution of general equation of structure) and showed the effect of reinforcement types and volume fraction, in addition to, showing the effect of sandwich honeycomb size.

The concluding remarks of the presented review showed that the studies focused on the mechanical properties and vibration analysis of honeycomb structure, in addition to, studying the buckling load of the beam structure. But, the study of the buckling load of honeycomb structure plate was little from the researchers, and, it was studied numerically and experimentally. In addition to, the analytical solution of buckling load was not presented in the previous papers, therefore, in this paper a presentation of the a suggested analytical solution of buckling load of honeycomb sandwich plate structure was done, by deriving the general equation of buckling plate, in addition to the numerical work and then a comparison of the evaluated results were done.

A SUGGESTED ANALYTICAL SOLUTION

A suggested analytical solution of buckling honeycomb sandwich plate included derive the general equation of sandwich plate from the principle equations of stress, forces, moments and displacement of plate is done. And then adding the mechanical properties of the honeycomb structure part of plate from the equations, (modulus of elasticity in 1 and 2-directions E_{h1} and E_{h2}, shear module G_{h12}, and Poisson's ratio ν_{h12} and ν_{h21}), shown, [3],

$$E_{h1} = \left(\frac{t}{l}\right)^3 \left(\frac{\cos\theta}{\left(\frac{h}{l}+\sin\theta\right).\sin^2\theta}\right) E,\ E_{h2} = \left(\frac{t}{l}\right)^3 \left(\frac{\left(\left(\frac{h}{l}\right)+\sin\theta\right)}{\cos^3\theta}\right) E,$$

$$G_{h12} = \left(\frac{t}{l}\right)^3 \left(\frac{\left(\left(\frac{h}{l}\right)+\sin\theta\right)}{\left(\frac{h}{l}\right)^2.\left(1+2.\left(\frac{h}{l}\right)\right).\cos\theta}\right) E$$

$$\nu_{h12} = \frac{\cos^2\theta}{\left(\frac{h}{l}+\sin\theta\right)\sin\theta},\ \nu_{h21} = \frac{\nu_{h12}E_{h1}}{E_{h2}} \tag{1}$$

Where, E is modulus of elasticity of honeycomb material and the dimensions of honeycomb part shown in Figure 1.

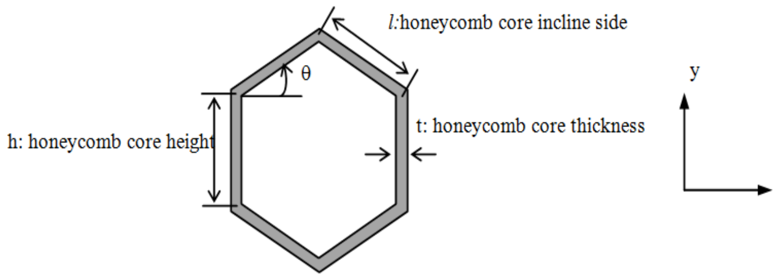


Figure 1: Dimensions of Honeycomb Part

And, the general equation of buckling orthotropic plate is, [29],

$$M_{x,xx} - 2M_{xy,xy} + M_{y,yy} = -q \quad (2)$$

Where, the bending moments per unit length are M_x, M_y, M_{xy}, and can be evaluated as,

$$M_x = \int_{-h/2}^{h/2} \sigma_{xx}.z\,dz,\ M_y = \int_{-h/2}^{h/2} \tau_{yy}.z\,dz,\ M_{xy} = \int_{-h/2}^{h/2} \tau_{xy}.z\,dz \quad (3)$$

And, q; is the buckling load supplied on the plate, and it's can be evaluated for applied load in the x-direction as, [30],

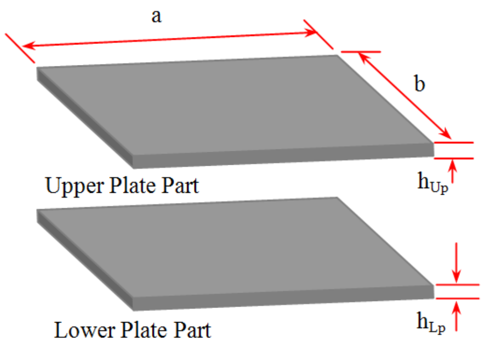
$$q = -N_x w_{,xx} \quad (4)$$

then, by substation Equation 4 into Equation 2, will get,

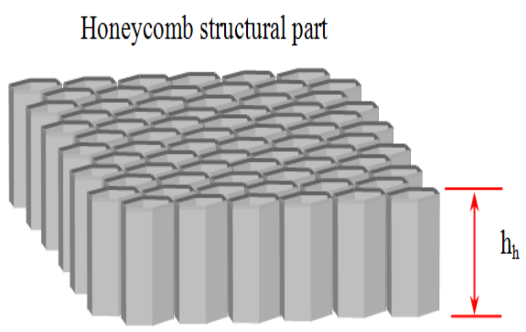
$$M_{x,xx} - 2M_{xy,xy} + M_{y,yy} = N_x w_{,xx} \quad (5)$$

The honeycomb sandwich plate studied in this work is combined with two parts as,

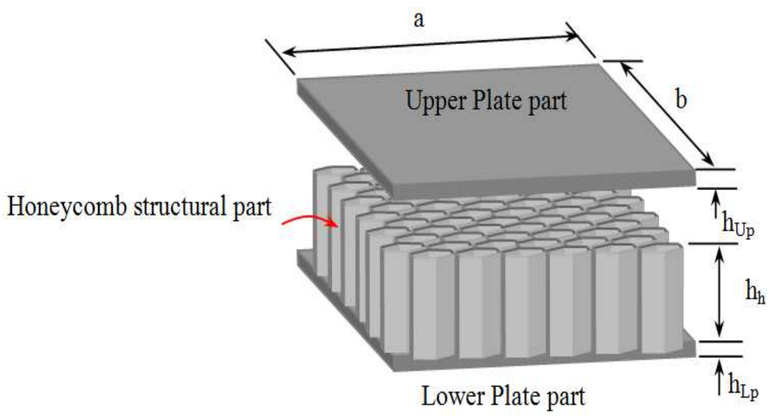
- The upper and lower plate parts. Their dimensions are shown in Figure 2 a.
- The honeycomb sandwich part. The dimensions are shown in Figure 2 b.
- Then the honeycomb sandwich plate structure included the dimensions as shown in Figure 2 c.



(a) Upper and Lower Plate Parts



(b) Honeycomb Sandwich Part



(c) Honeycomb Sandwich Plate Structure

Figure 2: Dimensions of Honeycomb Sandwich Combined Plate Structure

Therefore, the bending moment M_x, M_y, M_{xy} of honeycomb sandwich plate can be evaluated by substitution of the stresses of plate in each part through the Equation 3, as, [11],

$$M_x = \left(\int_{-\left(\frac{h_h}{2}+h_{Lp}\right)}^{-\left(\frac{h_h}{2}\right)} (\sigma_x)_{Lp}\, dz + \int_{-\left(\frac{h_h}{2}\right)}^{\left(\frac{h_h}{2}\right)} (\sigma_x)_h\, dz + \int_{\left(\frac{h_h}{2}\right)}^{\left(\frac{h_h}{2}+h_{Up}\right)} (\sigma_x)_{Up}\, dz\right)$$

$$M_y = \left(\int_{-\left(\frac{h_h}{2}+h_{Lp}\right)}^{-\left(\frac{h_h}{2}\right)} (\sigma_y)_{Lp}\, dz + \int_{-\left(\frac{h_h}{2}\right)}^{\left(\frac{h_h}{2}\right)} (\sigma_y)_h\, dz + \int_{\left(\frac{h_h}{2}\right)}^{\left(\frac{h_h}{2}+h_{Up}\right)} (\sigma_y)_{Up}\, dz\right)$$

$$M_{xy} = \left(\int_{-\left(\frac{h_h}{2}+h_{Lp}\right)}^{-\left(\frac{h_h}{2}\right)} (\tau_{xy})_{Lp}\, dz + \int_{-\left(\frac{h_h}{2}\right)}^{\left(\frac{h_h}{2}\right)} (\tau_{xy})_h\, dz + \int_{\left(\frac{h_h}{2}\right)}^{\left(\frac{h_h}{2}+h_{Up}\right)} (\tau_{xy})_{Up}\, dz\right) \tag{6}$$

Where, $(\sigma_x)_{Lp}, (\sigma_x)_h, (\sigma_x)_{Up}$ ... are the stresses of lower, honeycomb and upper part of plate structure in x, y, and xy-directions, evaluated as, [11],

$$(\sigma_x)_{Up} = -z\frac{E_{Up}}{(1-\nu_{Up}^2)}\left(\frac{\partial^2 w}{\partial x^2} + \nu_{Up}\frac{\partial^2 w}{\partial y^2}\right),\ (\sigma_y)_{Up} = -z\frac{E_{Up}}{(1-\nu_{Up}^2)}\left(\nu_{Up}\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right)$$

$$(\tau_{xy})_{Up} = -\frac{E_{Up}}{(1+\nu_{Up})}\, z\, \frac{\partial^2 w}{\partial x\, \partial y}$$

$$(\sigma_x)_h = -z\left(\frac{E_{h1}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial x^2} + \frac{\nu_{h12}E_{h2}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial y^2}\right),\ (\sigma_y)_h = -z\left(\frac{\nu_{h12}E_{h2}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial x^2} + \frac{E_{h2}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial y^2}\right)$$

$$(\tau_{xy})_h = -2G_{h12}\, z\, \frac{\partial^2 w}{\partial x\, \partial y}$$

$$(\sigma_x)_{Lp} = -z\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\left(\frac{\partial^2 w}{\partial x^2} + \nu_{Lp}\frac{\partial^2 w}{\partial y^2}\right),\ (\sigma_y)_{Lp} = -z\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\left(\nu_{Lp}\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right),$$

$$(\tau_{xy})_{Lp} = -\frac{E_{Lp}}{(1+\nu_{Lp})}\, z\, \frac{\partial^2 w}{\partial x\, \partial y} \tag{7}$$

Where, $E_{Up}, \nu_{Up}, E_{Lp}, \nu_{Lp}$ are the modulus of elasticity and Passion's ratio of upper and lower plate parts of plate structure, the respectively. And, w is the deflection of plate in z-direction. Therefore, by substation Equation 7 in to Equation 6 and then integration the results of equation to get,

$$M_x = -\left(\begin{array}{c} \frac{1}{3}\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\left(h_{Lp}^3 + 3\left(\frac{h_h}{2}\right)^2 h_{Lp} + 3\frac{h_h}{2}h_{Lp}^2\right)\left(\frac{\partial^2 w}{\partial x^2} + \nu_{Lp}\frac{\partial^2 w}{\partial y^2}\right) + \frac{2}{3}\left(\frac{h_h}{2}\right)^3\left(\frac{E_{h1}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial x^2} + \frac{\nu_{h12}E_{h2}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial y^2}\right) + \\ \frac{1}{3}\frac{E_{Up}}{(1-\nu_{Up}^2)}\left(h_{Up}^3 + 3\left(\frac{h_h}{2}\right)^2 h_{Up} + 3\frac{h_h}{2}h_{Up}^2\right)\left(\frac{\partial^2 w}{\partial x^2} + \nu_{Up}\frac{\partial^2 w}{\partial y^2}\right) \end{array}\right)$$

$$M_y = -\left(\begin{array}{c} \frac{1}{3}\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\left(h_{Lp}^3 + 3\left(\frac{h_h}{2}\right)^2 h_{Lp} + 3\frac{h_h}{2}h_{Lp}^2\right)\left(\nu_{Lp}\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right) + \frac{2}{3}\left(\frac{h_h}{2}\right)^3\left(\frac{\nu_{h12}E_{h2}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial x^2} + \frac{E_{h2}}{1-\nu_{h12}\nu_{h21}}\frac{\partial^2 w}{\partial y^2}\right) + \\ \frac{1}{3}\frac{E_{Up}}{(1-\nu_{Up}^2)}\left(h_{Up}^3 + 3\left(\frac{h_h}{2}\right)^2 h_{Up} + 3\frac{h_h}{2}h_{Up}^2\right)\left(\nu_{Up}\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right) \end{array}\right)$$

$$M_{xy} = -\left(\begin{array}{c} \frac{1}{3}\frac{E_{Lp}}{(1+\nu_{Lp})}\left(h_{Lp}^3 + 3\left(\frac{h_h}{2}\right)^2 h_{Lp} + 3\frac{h_h}{2}h_{Lp}^2\right)\frac{\partial^2 w}{\partial x\,\partial y} + \frac{4}{3}\left(\frac{h_h}{2}\right)^3 G_{h12}\frac{\partial^2 w}{\partial x\,\partial y} + \\ \frac{1}{3}\frac{E_{Up}}{(1+\nu_{Up})}\left(h_{Up}^3 + 3\left(\frac{h_h}{2}\right)^2 h_{Up} + 3\frac{h_h}{2}h_{Up}^2\right)\frac{\partial^2 w}{\partial x\,\partial y} \end{array}\right) \tag{8}$$

Then, by substitution of the bending moment of Equation 8 in to the general equation of buckling plate Equation 5, to get,

$$\left(\begin{array}{c} \left(\frac{1}{3}\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\begin{pmatrix} h_{Lp}^3 + 3\frac{h_h}{2}h_{Lp}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Lp}\end{pmatrix} + \frac{2}{3}\left(\frac{h_h}{2}\right)^3\frac{E_{h1}}{1-\nu_{h12}\nu_{h21}} + \frac{1}{3}\frac{E_{Up}}{(1-\nu_{Up}^2)}\begin{pmatrix} h_{Up}^3 + 3\frac{h_h}{2}h_{Up}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Up}\end{pmatrix}\right)\frac{\partial^4 w}{\partial x^4} + \\ \left(\frac{1}{3}\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\begin{pmatrix} h_{Lp}^3 + 3\frac{h_h}{2}h_{Lp}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Lp}\end{pmatrix} + \frac{2}{3}\left(\frac{h_h}{2}\right)^3\frac{E_{h2}}{1-\nu_{h12}\nu_{h21}} + \frac{1}{3}\frac{E_{Up}}{(1-\nu_{Up}^2)}\begin{pmatrix} h_{Up}^3 + 3\frac{h_h}{2}h_{Up}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Up}\end{pmatrix}\right)\frac{\partial^4 w}{\partial y^4} + \\ \left(\begin{pmatrix} h_{Lp}^3 + 3\frac{h_h}{2}h_{Lp}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Lp}\end{pmatrix}\frac{2}{3}\frac{E_{Lp}}{(1-\nu_{Lp})} + \frac{8}{3}\left(\frac{h_h}{2}\right)^3\left(\frac{\nu_{h12}E_{h2}}{1-\nu_{h12}\nu_{h21}} + G_{h12}\right) + \begin{pmatrix} h_{Up}^3 + 3\frac{h_h}{2}h_{Up}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Up}\end{pmatrix}\frac{2}{3}\frac{E_{Up}}{(1-\nu_{Up})}\right)\frac{\partial^4 w}{\partial x^2\,\partial y^2} \end{array}\right) = -N_x\frac{\partial^2 w}{\partial x^2} \tag{9}$$

To solve Equation 9 to evaluate the buckling load N_x, the behavior of the plate deflection as a function of x and y directions $w(x,y)$ must be evaluated, but, to evaluate $w(x,y)$, the boundary conditions of the plate are required. Then for simply supported plate can be used the boundary condition of the plate as, [31],

Edge $x = 0$ and $x = a$, $M_x = 0$ and $w = 0$

Edge $y = 0$ and $y = b$, $M_y = 0$ and $w = 0$

Then, by substitution of the boundary conditions of the simply supported the plate, into Equations. 8 and 9, to get the behavior of plate as a function of x and y directions, [32],

$$w = A\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b} \tag{10}$$

Therefore, substitution Equation 10 into Equation 9, to get the buckling load of honeycomb sandwich plate structure, for simply supported, with various upper, lower and honeycomb parts parameters effect, as,

$$N_x = \left[\begin{array}{c} \left(\frac{1}{3}\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\begin{pmatrix} h_{Lp}^3 + 3\frac{h_h}{2}h_{Lp}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Lp}\end{pmatrix} + \frac{2}{3}\left(\frac{h_h}{2}\right)^3\frac{E_{h1}}{1-\nu_{h12}\nu_{h21}} + \frac{1}{3}\frac{E_{Up}}{(1-\nu_{Up}^2)}\begin{pmatrix} h_{Up}^3 + 3\frac{h_h}{2}h_{Up}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Up}\end{pmatrix}\right)\left(\frac{m\pi}{a}\right)^2 + \\ \left(\frac{1}{3}\frac{E_{Lp}}{(1-\nu_{Lp}^2)}\begin{pmatrix} h_{Lp}^3 + 3\frac{h_h}{2}h_{Lp}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Lp}\end{pmatrix} + \frac{2}{3}\left(\frac{h_h}{2}\right)^3\frac{E_{h2}}{1-\nu_{h12}\nu_{h21}} + \frac{1}{3}\frac{E_{Up}}{(1-\nu_{Up}^2)}\begin{pmatrix} h_{Up}^3 + 3\frac{h_h}{2}h_{Up}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Up}\end{pmatrix}\right)\left(\frac{n\pi}{b}\right)^4\left(\frac{a}{m\pi}\right)^2 + \\ \left(\begin{pmatrix} h_{Lp}^3 + 3\frac{h_h}{2}h_{Lp}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Lp}\end{pmatrix}\frac{2}{3}\frac{E_{Lp}}{(1-\nu_{Lp})} + \frac{8}{3}\left(\frac{h_h}{2}\right)^3\left(\frac{\nu_{h12}E_{h2}}{1-\nu_{h12}\nu_{h21}} + G_{h12}\right) + \begin{pmatrix} h_{Up}^3 + 3\frac{h_h}{2}h_{Up}^2 \\ +3\left(\frac{h_h}{2}\right)^2 h_{Up}\end{pmatrix}\frac{2}{3}\frac{E_{Up}}{(1-\nu_{Up})}\right)\left(\frac{n\pi}{b}\right)^2 \end{array}\right] \tag{11}$$

Where, a, b are plate length and width respectively, and, $n = m = 1$. The value of the critical buckling load of

Equation 11, can be evaluated by building a program using Fortran Power Station Ver. 4.0. Where, the input data required of the program are, the mechanical properties of upper, lower, and honeycomb parts of a plate and the parameters change in the program are the upper, lower and honeycomb part thickness and honeycomb part dimensions, in addition to, the core size of honeycomb structure parts. Therefore, can be get the buckling load of the honeycomb plate structure, as simply supported boundary conditions, with various parameters of sheet plate and core honeycomb part effect as the output of a program.

NUMERICAL INVESTIGATION

The numerical techniques are used to evaluate the approximate values of results, [33-43], in addition to, the numerical techniques are used to prove the accuracy of results evaluated by other technique, by comparison, the results together. The buckling load of honeycomb sandwich structure with various honeycomb size effect is evaluated by using finite element method with using Ansys program, using the numerical technique. Thus, the finite element method needs to select the element types for problem application, [44-48], therefore, to evaluate the buckling load of honeycomb structure a SOLID 168, 3-D, 10-node, dynamic element must be selected. Since, the honeycomb structure is orthotropic structure, and then, since its element solving the behavior of this structure so that it was selected. Therefore, the element characterizations and geometry are having 3-degrees of freedom at each nodes, also, it have 10-nodes, as shown in Figure 3, [49], and the element application of orthotropic materials, in addition to, the elements is selected for other materials as isotropic; anisotropic; plastic; viscoelastic; rubber materials etc.

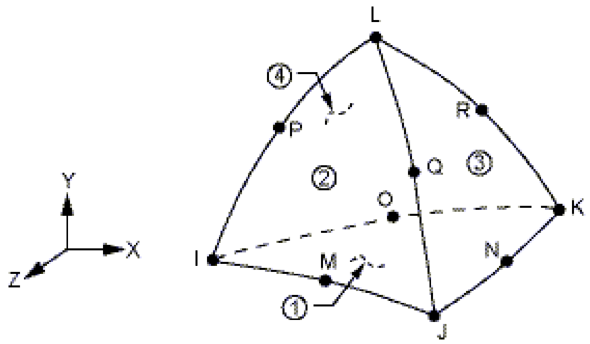


Figure 3: Geometry of Element SOLID-168

Thus, the Ansys program required multi-input to evaluate the buckling load, as out-put, of the honeycomb structure. Then, the input data required are,

- Mechanical properties of upper and lower sheet plate structure, in addition to, mechanical properties for honeycomb structure plate.
- Dimension, length; width and thickness, for upper and lower sheet plate parts.
- Dimension, length; with; thickness and core size, for honeycomb structure part.
- Boundary conditions for plate structure.

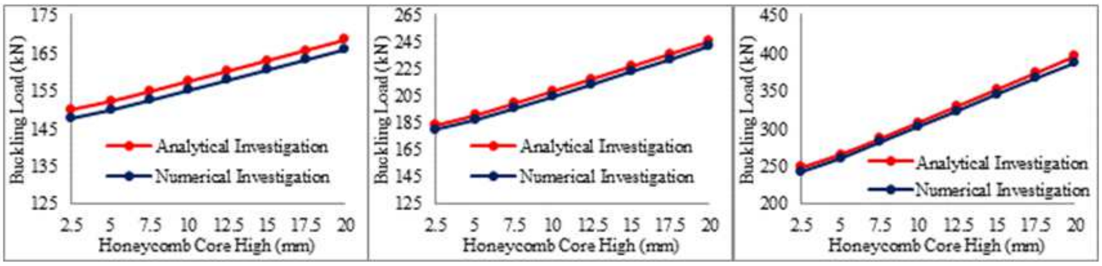
Therefore, the out-put of Ansys program is the buckling load of honeycomb plate structure with various sheet plate parts and honeycomb structure parametric effect. Then, the comparison was done for the buckling load numerical results with buckling load analytical results, to shows the agreement between the two techniques were used.

RESULTS AND DISCUSSIONS

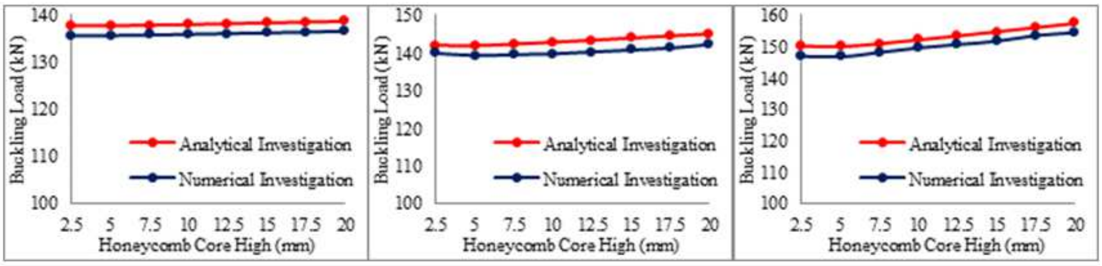
The results included the mechanical properties of the honeycomb structure part are evaluated using the analytical solution of honeycomb structure technique. After the evaluation of mechanical properties, the buckling load of sandwich structure combines from upper and lower plate and honeycomb core structure is estimated. The analytical and numerical investigations are used to evaluate the buckling load of sandwich plate structure with various parameters study. The size of the honeycomb part, upper, lower and honeycomb plate thickness parts, and the effect of supported types of a plate on the buckling load of the plate structure.

The sandwich plate structure is combined from Aluminum materials for upper, lower and honeycomb parts, with the modulus of elasticity $E = 75\ GPa$ and Poisson's ratio is 0.3. Also, the length and width of plate structure used are $a = b = 0.5\ m$, and thickness for upper and lower plate are $h_{lp} = h_{up} = 1\ mm$, with various values of thickness for honeycomb part. Then the first step of investigation is the comparison between the evaluated analytical and numerical buckling load results to show the agreement and accuracy of these results, with various core size dimensions effect and various honeycomb thickness with core angle $\theta = 45^o$, as shown in Figures 4. I and II, respectively. From figures, it can be seen that the maximum discrepancy of results are about (2.24%). Therefore, these showed that the results of the analytical technique can be adopted with the comparison of numerical techniques, by using finite element method, with using of ANYSY program.

The effect of honeycomb core size on the buckling load of the plate structure is shown in Figure 5. and Figure 6. with core angle $\theta = 45^o$, for honeycomb thickness part $h_h = 5\ and\ 7.5\ mm$, respectively. Figure 7 showed that the buckling load is increased with the increasing of honeycomb core thickness and height. But, the buckling loads for honeycomb sandwich plate structure were decreased with the increasing the honeycomb core incline side, as shown in Figures 8. In addition, the buckling loads were increased with increasing of the honeycomb part thickness. It can be concluded that the increase of honeycomb core thickness will lead to modifying the mechanical properties of the honeycomb part, then, the buckling load is increased. Also, since the increase for honeycomb core incline side leads to decreasing the mechanical properties for the honeycomb part, then, the buckling loads are decreased. In addition, the increase of honeycomb part thickness leads to modify the stiffness for structure, therefore, the increase of honeycomb part thickness leads to increase the buckling load for the sandwich plate structure.

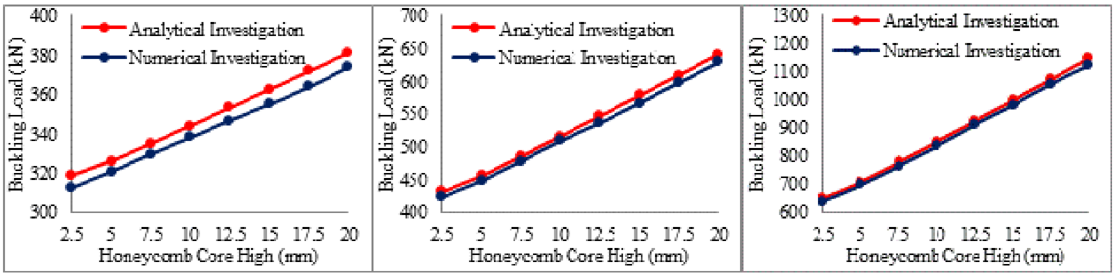


(a) t = 1 mm, l = 2.5 mm (b) t = 1.5 mm, l = 2.5 mm (c) t = 2 mm, l = 2.5 mm

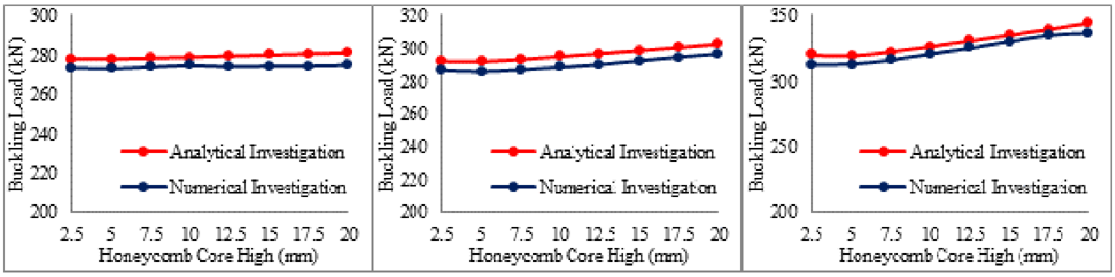


(d) t = 1 mm, l = 5 mm (e) t = 1.5 mm, l = 5 mm (f) t = 2 mm, l = 5 mm

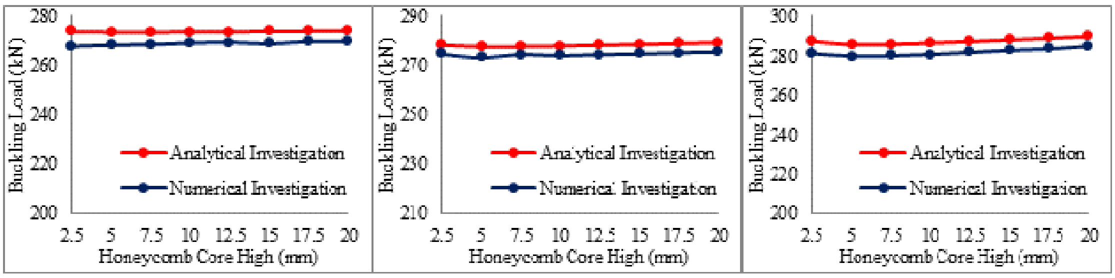
I. Honeycomb Structure Thickness $h_h = 5\ mm$



(a) t = 1 mm, l = 2.5 mm (b) t = 1.5 mm, l = 2.5 mm (c) t = 2 mm, l = 2.5 mm



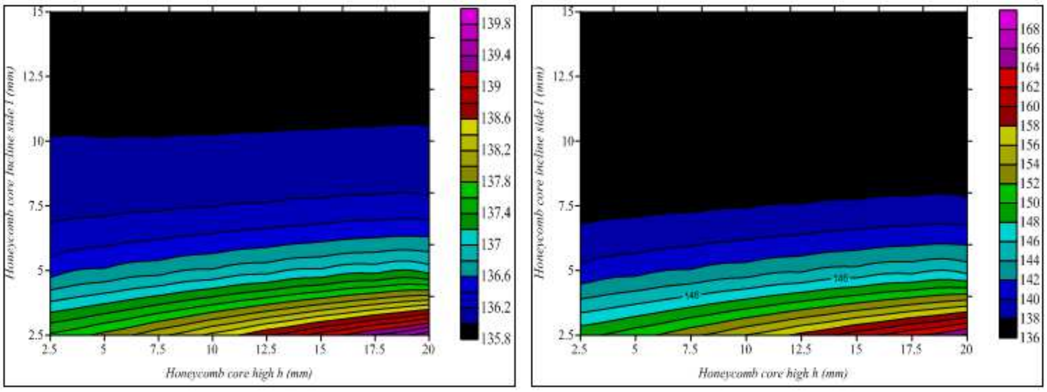
(d) t = 1 mm, l = 5 mm (e) t = 1.5 mm, l = 5 mm (f) t = 2 mm, l = 5 mm



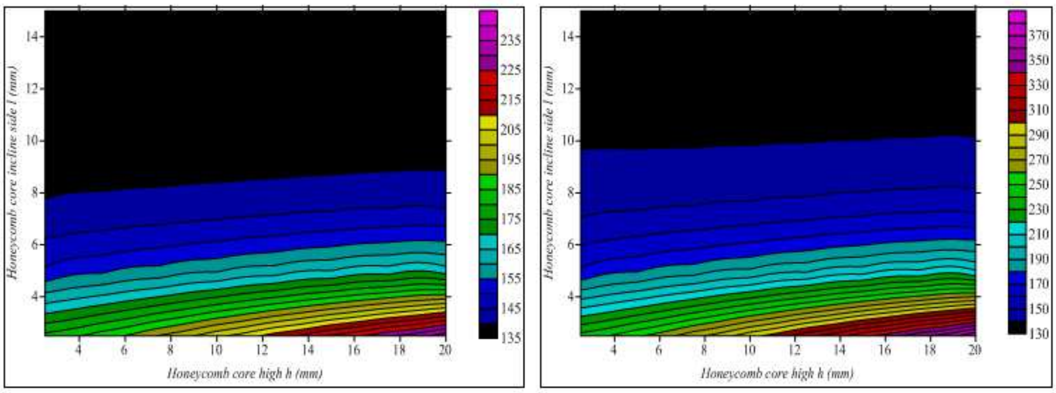
(g) t = 1 mm, l = 7.5 mm (h) t = 1.5 mm, l = 7.5 mm (i) t = 2 mm, l = 7.5 mm

II. Honeycomb Structure Thickness $h_h = 7.5$ mm

Figure 4: Comparison for Buckling Load (kN) Results Between Analytical and Numerical Investigation

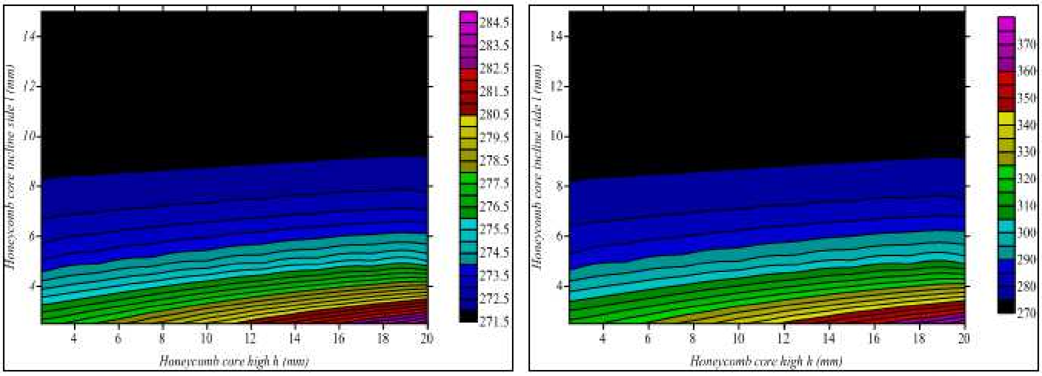


(a) Honeycomb Core Thickness t = 0.5 mm (b) Honeycomb Core Thickness t = 1 mm.

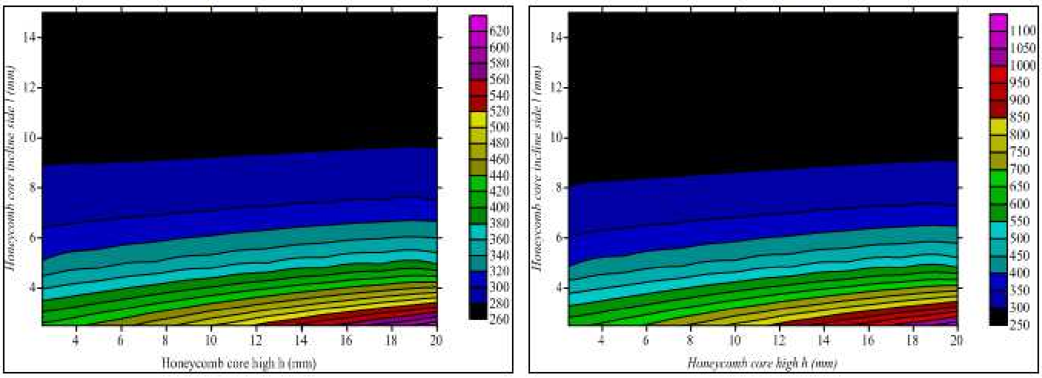


(c) Honeycomb Core Thickness t = 1.5 mm (d) Honeycomb Core Thickness t = 2 mm.

Figure 5: Buckling Load (kN) for Plate with Honeycomb Thickness (5 mm)

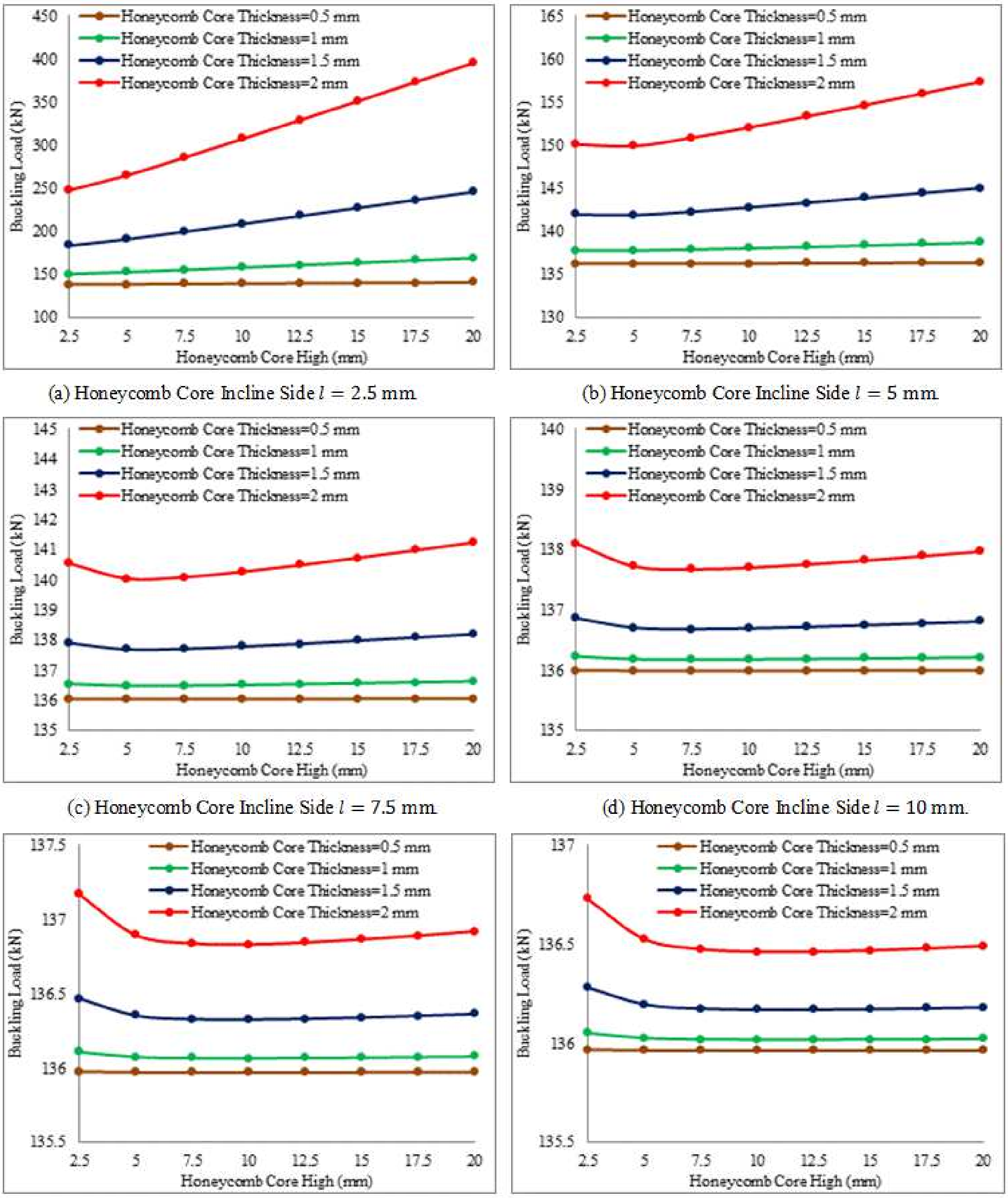


(a) Honeycomb Core Thickness t = 0.5 mm. (b) Honeycomb Core Thickness t = 1 mm.



(c) Honeycomb Core Thickness t = 1.5 mm. (d) Honeycomb Core Thickness t = 2 mm.

Figure 6: Buckling Load (kN) for Plate with Honeycomb Thickness (7.5 mm)



(a) Honeycomb Core Incline Side $l = 2.5$ mm

(b) Honeycomb Core Incline Side $l = 5$ mm

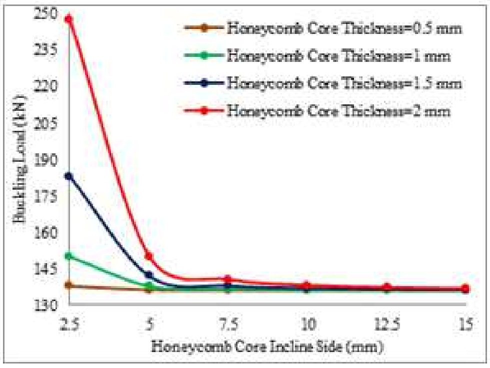
(c) Honeycomb Core Incline Side $l = 7.5$ mm

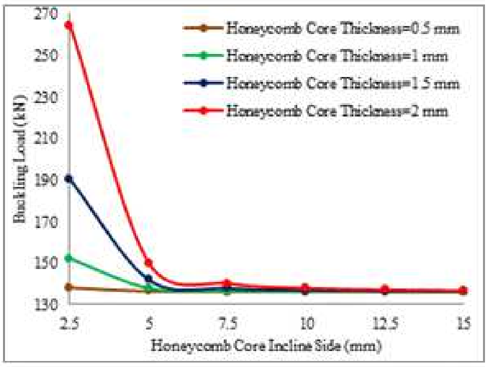
(d) Honeycomb Core Incline Side $l = 10$ mm.

(e) Honeycomb Core Incline Side l = 12.5 mm

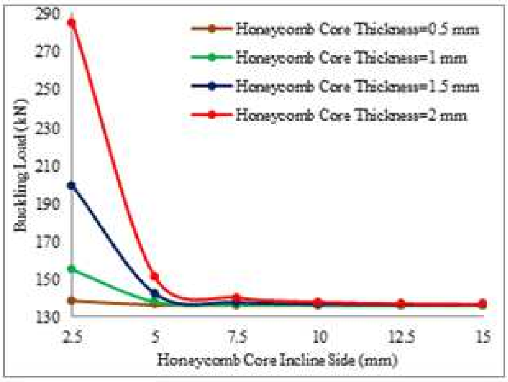
(f) Honeycomb Core Incline Side l = 15 mm

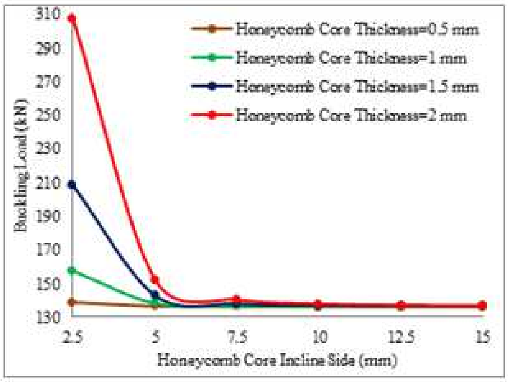
Figure 7: Buckling Load for Sandwich Plate with Various Honeycomb Core Height and Thickness Effect, for $h_h = 5$ mm



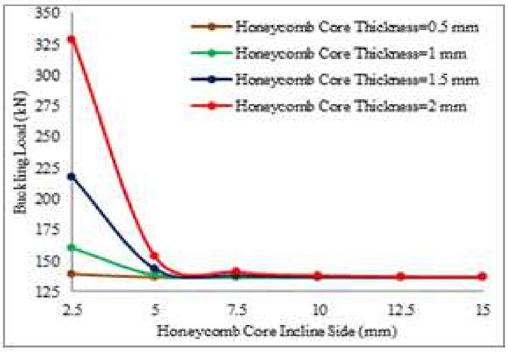


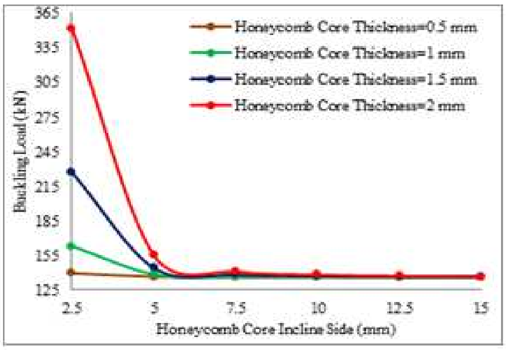
(a) Honeycomb Core Height $h = 2.5$ mm (b) Honeycomb Core Height $h = 5$ mm



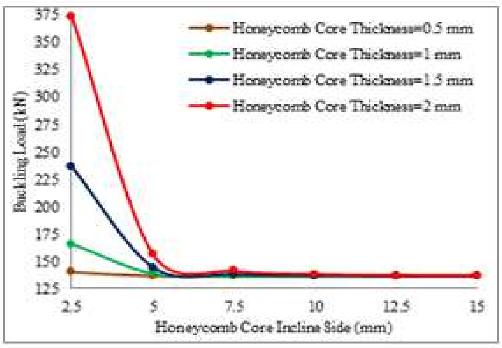


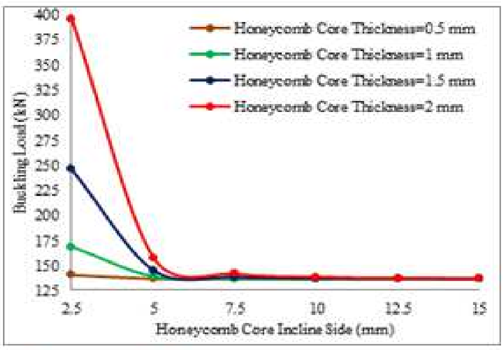
(c) Honeycomb Core Height $h = 7.5$ mm (d) Honeycomb Core Height $h = 10$ mm





(e) Honeycomb Core Height $h = 12.5$ mm (f) Honeycomb Core Height $h = 15$ mm





(g) Honeycomb Core Height $h = 17.5$ mm (h) Honeycomb Core Height $h = 20$ mm

Figure 8: Buckling Load for Sandwich Plate with Various Honeycomb Core Incline Side Effect, for $h_h = 5$ mm

CONCLUSIONS

In the presented work, the effect of honeycomb core size on the critical buckling behavior for sandwich plate structure was studied. Where, the investigation includes a suggested analytical solution of a general equation of buckling behavior of plate, in addition to a comparison of this analytical buckling load results with results evaluated numerically by finite element techniques, to show the agreement of analytical investigation suggested. The conclusions of this work can be summarized as,

- The suggested analytical solution is a good tool can be used to evaluate the buckling behavior for honeycomb sandwich plate structure with the effect of various honeycomb core sizes and other parameters effect. The comparison with numerical investigation presented using finite element method gives a good agreement for evaluated results with a maximum error about (2.24%).
- The increase of honeycomb core thickness and height lead to modifying the mechanical properties for the honeycomb part structure, therefore, this modification leads to increasing the buckling behavior for honeycomb sandwich plate structure. In addition, the increase of buckling load for plate structure, with honeycomb core thickness greater than 1 mm, was more than the increase of buckling load for it with honeycomb core thickness less than 1 mm.
- The buckling load for honeycomb sandwich plate structure was decreased with increasing of the honeycomb core incline side size. Where, the decreasing of buckling load was a result of the change of the honeycomb core incline side form $2.5\ to\ 5\ mm$. This decrease was more than that resulted from the decreasing of buckling load with changing of other values of core incline side.
- The increase of honeycomb structure part thickness led to modify the structure buckling stiffness by increasing its value.
- Finally, the increasing of honeycomb size did not modify the mechanical properties, and then, the other behaviors for structure. But the mechanical properties and behavior of structure are affected by the change of all other dimensions for honeycomb core. Therefore, the core size must be selected depending on the required mechanical behavior for structure, depending on the structure application.

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